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Title: Pathfinding and Localization for Multi Agent Problems

Introduction

A key challenge in allocating parking lots to a plethora of drivers in real time lies in the ability to identify the exact location, orientation and heading of each vehicle while simultaneously solving for the optimal allocation of parking spaces that satisfy several constraints. These constraints include knowing the type of parking lot needed by individual drivers (handicap or EV lots, for example), ensuring that the average waiting time for each driver to find a suitable lot is reduced and dynamically routing drivers to available parking spaces in a manner that prevents collision and is agnostic to potential obstacles. The need for an efficient algorithm that accurately localizes each vehicle and routes them dynamically in real time is the motivation behind this technical review paper, which aims to summarize state-of-the-art methods used in multi-agent path planning and localization.

Localization

A WiFi-based localization system has been developed in an indoor parking space to direct vehicles to available lots[1]. This technology requires a network of wireless access points to be set up at various locations of the carpark. When the end user connects to the WiFi network, the distance of the end user to each of the access points can be calculated based on the strength of the WiFi connections to each access point. With this information, the exact location of the end user and his or her direction of motion can be calculated using the weighted nearest neighbour method. As long as the user is connected to three or more access points, the position of the end user can be calculated. This technology works in a similar method to that of GPS satellite positioning but is the preferred method for localization in indoor spaces as the GPS signal is not as reliable without direct line of sight.

Using WiFi as a means of localization is likely to be a low-cost solution because of how inexpensive access points are and the fact that it works well in an indoor environment means that it is a viable solution for indoor or sheltered carparks. However, a huge drawback of the use of WiFi for localization is that the range of WiFi communication is limited, so a large network of access points is mandatory to cover a large area. A key consideration for implementing this technology is that not all end users who want to park their vehicles have smartphones or are willing to connect their mobile devices to the network. In this case, it may lead to the localisation system failing to identify these vehicles and could potentially lead to errors in routing vehicles.

To tackle this problem, vision-based localization systems can be used instead. They often encompass both hardware and software components which work in tandem. Cameras that are specifically designed to identify vehicles in real time are available in the market; the FLIR TrafiCam x-stream 2[2] is a good example. This camera outperforms its competitors in the market because it provides 25 fps video streaming with a built-in vehicle detection algorithm. Its IP67 weatherproof rating also makes it a good choice for outdoor use. Yet, the camera's narrow field of view is its most major drawback.

In the case that one camera alone cannot cover the entire carpark, multiple cameras can be used to capture different areas of the parking space. This network of cameras provides a central computer with the information necessary to localize each vehicle in the carpark. Drawing parallels to the CCTV systems used in industrial sites by R. Stahl Camera Systems[3], the video feed from multiple cameras can be streamed to a server that processes the feed from each camera to provide the central computer with the localization data of all the vehicles in the carpark.

Path Planning

Having accurate localization data forms the bedrock for the path planning algorithms. The gist of multi-agent path planning algorithms is to find the best path for individual agents to move in an environment with other agents while maximizing the overall efficiency of all the paths in a span of time. This problem is challenging to tackle because the complexity of the problem scales exponentially with the number of agents and constraints in the environment.

Pathfinding algorithms rely on two primary steps[4]. Firstly, the observed space is discretized into a grid so that a graph of the obstacles and the space free of obstacles can be generated. Obstacles that are detected will occupy grids that cannot be traversed in the graph. Grids that do not have any obstacles present can then be considered as a viable path for agents to move to. Next, the search algorithm returns the most optimal path based on some heuristic function. The objective of the algorithm is to minimize the overall user-defined cost of the path based on this heuristic function.

A method proposed by Koenig et al relies on using conflict-based search with highways[5] to obtain the ideal path for each agent. For each proposed path of one agent, additional constraints are added to the paths of the other agents to prevent them from colliding. The cell in which an agent is present at a certain point in time will be marked as a constraint for the path of the other agents at that particular time. The algorithm then performs a graph search to find the optimal path for each agent independently given the constraints imposed by the paths of the other agents.

Similarly, Andreychuk et al proposes the use of a continuous-time conflict-based search algorithm to optimally identify multi-agent paths[6]. The algorithm computes the minimal time in which each agent can move to its next location without collision. The conflict detection algorithm identifies collisions that happen due to the actions of the agents at specific times. To reach the optimal paths, unsafe intervals of time are calculated to ascertain the time a particular action of one agent conflicts with that of another agent and added as constraints to the latter.

Conclusion

Advances in both localization methods and path planning algorithms are form the bedrock of assigning available parking lots to drivers. The accuracy and computing resources needed to complete this task will impact the user experience greatly. Hence, it is imperative that drivers are given paths that results in time saved circling an otherwise busy carpark so that they trust the directions given to them.

References

1. Y. Han, J. Shan, M. Wang and G. Yang, "Optimization design and evaluation of parking route based on automatic assignment mechanism of parking lot," *Advances in Mechanical Engineering*, vol. 9, no. 7, pp. 1-9, 2017, doi: 10.1177/1687814017712416.
2. FLIR, "FLIR TrafiCam x-stream2.", Teledyne Flir. https://www.flir.com/products/flir-traficam-x-stream2/ (accessed Oct. 7, 2021).
3. R. Stahl Camera Systems, "State-of-the-Art Cameras and CCTV Systems," R. Stahl Camera Systems, Koln, Germany, 2016.
4. Z. A. Algfoor, M. S. Sunar and H. Kolivand, "A Comprehensive Study on Pathfinding Techniques for Robotics and Video Games", *Int. Journal of Computer Games Technology*, vol. 2015, Apr 2015, doi: 10.1155/2015/736138.
5. S. Koenig. (2017). Multi-Agent Path Finding [Powerpoint slides]. Available: http://idm-lab.org/slides/mapf-tutorial.pdf
6. A. Andreychuk, K. Yakovlev, D. Atzmon and R. Sternr, "Multi-Agent Pathfinding with Continuous Time," *Proc. 28th Int. Joint Conf. on Artificial Intelligence*, 2019.